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# Evaluation of *Dicyphus hesperus* for biological control of sweet potato whitefly and potato psyllid on greenhouse tomato

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**Abstract** The potato psyllid, *Bactericera cockerelli* Sulcer (Hemiptera: Psyllidae), and the sweetpotato whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), are major pests in tomato in the USA, Mexico, and Central America. Earlier research revealed that the mirid bug *Dicyphus hesperus* Athias-Henriot (Heteroptera: Miridae) has favorable rates of development and reproduction when reared on whitefly and psyllid and is able to provide good control of both pests on tomato in cage experiments. Consequently it could have potential as a biological control agent of these pests. Nevertheless, it has yet to be demonstrated that the addition of *D. hesperus* to existing biological control programmes improves management of these pests in commercial tomato greenhouses. In the present study, experiments were designed to evaluate *D. hesperus* as a predator of *B. tabaci* and *B. cockerelli* in tomato in large cages simulating commercial greenhouse conditions in two different cropping seasons (fall-winter and summer) in two subsequent experiments. In each season, a randomized complete block design was used with three replicates and two treatments: (1) No *D. hesperus*, receiving *B. tabaci* and *B. cockerelli*, and (2) *D. hesperus*, receiving *B. tabaci* and *B. cockerelli* as No *D. hesperus* plus *D. hesperus*. The predator established and reproduced well in the crop and also provided significant reduction of the whitefly and psyllid populations in both cropping seasons. In addition, no evidence of plant damage on either leaves or flower was observed, although a little fruit damage of presumably non-economic significance was recorded. Our results demonstrate that implementation of augmentative releases of *D. hesperus* would improve biologically-based management strategies in tomato and presumably help to increase adoption of such programmes in tomato in North America.

**Keywords** Tomato · Miridae · *Bemisia tabaci* · *Bactericera cockerelli* · Biological control

## Introduction

The potato psyllid, *Bactericera cockerelli* Sulcer (Hemiptera: Psyllidae), and the sweetpotato whitefly,

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*Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), are major pests in tomato in the USA, Mexico, and Central America (Butler and Trumble 2012a; Garzón-Tiznado et al. 2009). Both species produce direct feeding damage by debilitating the plant, producing honeydew that serves as a substrate for sooty mold, and in the case of the whitefly, inducing the physiological disorder of tomato irregular ripening (Schuster 2001). However, they are even more important due to their role in transmission of plant viruses and bacteria (Jones 2003; Butler and Trumble 2012a) which causes high economic losses. Chemical control of the potato psyllid and the whitefly is becoming progressively difficult, and thus interest in alternative control methods such as integrated pest management (IPM) strategies is increasing. These methods combine biological control and synthetic pesticides among other tools, providing additional control options to growers. The list of natural enemies of *B. cockerelli* in North America includes several parasitoids and predators (Butler and Trumble 2012a, b). Among the parasitoids, there are two primary parasitoids, *Metaphycus psyllidis* Compere (Hymenoptera: Encyrtidae) and *Tamarixia triozae* (Burks) (Hymenoptera: Eulophidae) (Butler and Trumble 2012b). *Tamarixia triozae* has demonstrated some potential for psyllid control in some regions (Banks 2012; Rojas et al. 2015; Workman and Whiteman 2009). However, the present *B. cockereilli*-tomato rearing system has produced inefficient results with control of *T. triozae*. This is due primarily to the fact that the relatively large numbers of parasitoids needed for adequate control make it uneconomic. Moreover, in some crops such as tomato, it might not prevent disease transmission by the psyllid (Rojas et al. 2015). Among the predators, none of them have been demonstrated to be effective on a large commercial scale under greenhouse conditions (Butler and Trumble 2012a, b).

Biocontrol of whitefly in tomato in North America has been typically achieved by releasing the parasitic wasps *Eretmocerus eremicus* Rose and Zolnerowich and *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) (Greenberg et al. 2002; Hoddle and van Driesche 1999; van Driesche et al. 2001a). However, this approach requires weekly releases of the parasitoids and often has to be supplemented with pesticide applications (van Driesche et al. 2001b). In contrast, IPM programmes in Europe for tomato are based on the introduction of generalist mirid predators, particularly *Macrolophus pygmaeus* Wagner and *Nesidiocoris tenuis* Rambur (Heteroptera: Miridae) due to their high effectiveness against whitefly and the invasive pest *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) (Avilla et al. 2004; Calvo et al. 2009, 2012a, 2012b; Urbaneja et al. 2009, 2012). This approach has proven very effective and it is presently implemented in more than 8000 ha of tomato greenhouses (Calvo et al. 2012c). Adaptation of such methods into North America could reduce the use of insecticides in tomato crops and increase adoption of IPM.

However, importation of exotic natural enemies, such as *M. pygmaeus* and *N. tenuis*, is not currently being pursued in North America due to concerns over their potential impact on non-target species and potential risk of injury to crop (Albajes et al. 2006; Castañé et al. 2011; Cock et al. 2009; Parry 2009; van Lenteren et al. 2006). We therefore initiated a research project to search for native natural enemy to North America with the characteristics of the above-mentioned predators. Different areas were surveyed and *Dicyphus hesperus* Knight (Heteroptera: Miridae), which is widely distributed and native to North America (Henry and Wheeler 1988), was among the collected species. This mirid had previously been investigated as an agent for biological control of pests of greenhouse grown tomatoes (Gillespie et al. 2007; Shipp and Wang 2006). These authors found that the predator was able to establish in tomato greenhouses, suppress populations of different pests, including the sweetpotato whitefly and the western flower thrips *Frankliniella occidentalis* Pergande (Thysanoptera: Thripiidae) and had tolerable levels of plant feeding. These findings correlated with our own observations. In earlier laboratory and cage experiments, *D. hesperus* exhibited good developmental and reproductive rates when reared on whitefly and psyllid and we found that releases of *D. hesperus* on tomato in cage experiments provided good control of the sweetpotato whitefly and psyllid, either alone or together, and plant feeding would not have an economic impact (Calvo et al. unpublished data). However, these preliminary results need to be confirmed on a large commercial scale and actual greenhouse conditions before the predator can be recommended as a biological control agent in commercial crops. Experiments were designed to evaluate *D. hesperus* as a biological control agent against *B. tabaci* and *B. cockerelli* on tomato in large cages simulating realistic commercial greenhouse conditions in two different cropping seasons (fall-winter and summer) in two experiments.

## Materials and methods

### Insects and supplementary food

Eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) used as supplementary food during the experiments were obtained from the commercial product Entofood$^{\mathrm{TM}}$ (Koppert Biological Systems, Berkel en Rodenrijs, The Netherlands). *Dicyphus hesperus* adults were obtained from a rearing colony maintained on tomato plants with eggs of *E. kuehniella* as food. Adult pests (*B. tabaci* and *B. cockerelli*) were obtained from rearing colonies maintained on tomato for several generations before the start of the experiment and originally collected on tomato in several locations within Mexico.

### Greenhouses

The experiments were conducted in three 180 m$^2$ adjacent multi-tunnel greenhouses, each divided into two 90 m$^2$ sectors (plots) and located in the Colegio de Postgraduados in Texcoco (Mexico State, Mexico). Plots within the same greenhouse were separated with a polyethylene screen with 220 × 331 µm interstices and the floor was covered with woven 2-mm-thick polyethylene cloth. All plots had separate auto-operated roof and side vents and access was through an independent sliding double doorway sealed with plastic. All vents were sealed with the same screen used to separate plots. The greenhouse was equipped with a heating system. Temperature and relative humidity were monitored in three plots, each belonging to a different greenhouse, with a HOBO H8 RH/Temp Loggers (Onset Computer, Bourne, MA, USA).

### Ambient conditions

The average daily temperature and RH ranged during the fall-winter experiment between 10.0 ± 1.03 to 20.9 ± 0.82 °C and 66.7 ± 0.67 to 87.1 ± 0.67 %, respectively, whereas they ranged from 13.7 ± 0.15 to 29.7 ± 0.03 °C and 38.2 ± 0.02 to 81.9 ± 0.00 %, respectively during the summer experiment.

### Experimental design and procedure

Two treatments were compared in both experiments (cropping seasons) in a complete randomized block design with three replicates (each in a greenhouse) in which each treatment was randomly designated for each sector (plot) within each greenhouse. Treatments were: (1) No *D. hesperus*, receiving potato psyllid and sweetpotato whitefly only (Table 1), (2) *D. hesperus*, receiving potato psyllid and sweetpotato whitefly as released in No *D. hesperus* plus *D. hesperus*.

In plots receiving *D. hesperus*, eggs of *E. kuehniella* were used as supplemental food during the experiments at a rate of 0.004 g per plant per week. Additions began just after the predator release and continued weekly for five weeks thereafter. An additional treatment with no supplemental food would have been more conventional, but *D. hesperus* nymphs are incapable of reaching maturity in the absence of prey on tomato (Sánchez et al. 2004) and availability of food (whitefly and psyllids) after planting was expected to be insufficient. Predation of *D. hesperus* on *E. kuehniella* eggs also increases its fecundity, pre-imaginal survival and lifetime of the predator (Sánchez et al. 2004) and thus supplementary food was added to increase the likelihood of establishment. In addition, use of supplemental food is common with other mirid predators (Calvo et al. 2009, 2012a, b) and its use would simulate practically relevant conditions.

For all treatments in both cropping seasons, seeds of tomato *Lycopersicum esculentum* L. cv. Merlice (De Riuter, St. Louis, Missouri, USA) were sown into peat moss, and subsequently transplanted into 15 l coco peat fiber bags inside the above-described plots when they reached the fifth leaf stage. Day of planting was 20/09/2013 and 03/07/2014 for the fall-winter and summer experiment, respectively. For each plot 250 and 215 plants were placed in the fall-winter and summer experiment, respectively. Crop cultivation techniques typical for greenhouse tomato cultivation were followed whereby plants were trained by the main stem to a black polyethylene string tied to a stainless steel overhead wire. Secondary shoots were removed and water and fertilizer were supplied as required through an automatic drip irrigation system.

**Table 1** Timing and rate for *Bemisia tabaci* (Wf) and *Bactericera cockerelli* (Bc) releases during the fall-winter and summer experiments

| fall-winter | | summer | |
|---|---|---|---|
| Date | Rate (Adults per plant) | Date | Rate (Adults per plant) |
| 20/9/2013 | 2 Wf + 0.2 Bc | 3/7/2014 | 1 Wf + 0.1 Bc |
| 27/9/2013 | 2 Wf + 0.2 Bc | 10/7/2014 | 1 Wf + 0.1 Bc |
| 4/10/2013 | 2 Wf + 0.2 Bc | 17/7/2014 | 1 Wf + 0.1 Bc |
| 11/10/2013 | 2 Wf + 0.2 Bc | 24/7/2014 | 1 Wf + 0.1 Bc |
| 18/10/2013 | 2 Wf + 0.2 Bc | 31/7/2014 | 1 Wf + 0.1 Bc |
| 25/10/2013 | 2 Wf + 0.2 Bc | 7/8/2014 | 1 Wf + 0.1 Bc |
| 1/11/2013 | 1 Wf + 0.1 Bc | 14/8/2014 | 1 Wf + 0.1 Bc |
| 8/11/2013 | 1 Wf + 0.1 Bc | 21/8/2014 | 1 Wf + 0.1 Bc |
| 15/11/2013 | 1 Wf + 0.1 Bc | 28/8/2014 | 2 Wf + 0.2 Bc |
| 22/11/2013 | 1 Wf + 0.1 Bc | 4/9/2014 | 2 Wf + 0.2 Bc |
| 29/11/2013 | 1 Wf + 0.1 Bc | 11/9/2014 | 2 Wf + 0.2 Bc |
| 6/12/2013 | 1 Wf + 0.1 Bc | 18/9/2014 | 2 Wf + 0.2 Bc |
| 13/12/2013 | 1 Wf + 0.1 Bc | 25/9/2014 | 2 Wf + 0.2 Bc |
| 20/12/2013 | 1 Wf + 0.1 Bc | 2/10/2014 | 2 Wf + 0.2 Bc |
| Total | 20 Wf + 2 Bc | | 20 Wf + 2 Bc |

Release rate for *B. tabaci* and *B. cockerelli* was the same for all treatments (Untreated and *D. hesperus*) within the same experiment

## Predator and pests releases

*Dicyphus hesperus* was released at once just after planting and at a rate of one predator per plant. Timing and rate for the predator release were chosen based on recommended release methods for other commercially available mirid bugs (Calvo et al. 2009, 2012a, b, c). Predator adults were first cooled briefly in a cold room at 8 °C for counting before being released into the plots at a sex ratio of 1:1. They were distributed uniformly in the crop at five release spots per plot, providing each spot with ca. 50 adults as it is the normal procedure for other mirid species (Calvo and Urbaneja 2004). Whitefly adults for infestation were transferred into 50 ml plastic cups, each containing 50 adults which were distributed regularly throughout each plot. Psyllid adults for infestation were transferred into 60 ml plastic cups with a tomato leaf-disk on a fine layer of 2 % w/vol. agar, each containing three pairs of *B. cockerelli* which were distributed regularly throughout each plot. The number of bottles containing whitefly or psyllid adults to be placed per plot was adjusted to release the amounts showed in Table 1. This release schedule was intended to simulate gradual immigration of both pests into the greenhouse and rates for pest releases varied throughout the experiment to simulate progressively lower or higher pest influxes during the fall-winter and summer experiment respectively, as it is the normal situation in winter and summer greenhouse plantations. Potato psyllid and whiteflies adults to infest the tomato plants were collected each week from a single cohort to assure homogeneity of age and sex ratio.

## Pesticide and fungicide use

During the fall-winter experiment spiromesifen (Oberon$^{TM}$; Bayer Crop Science, Germany) was sprayed for *Aculops lycopersici* Massee (Acari: Eryophidae) control in all plots on 25/10/2014. Azoxistrobin (Amistar Gold$^{TM}$; Syngenta, Switzerland) and mancozeb (Mancozeb 80 PH$^{TM}$, Adama, Mexico) were also sprayed in all plots during the fall-winter experiment on 01/12/2013 and 19/09/2013, respectively for *Alternaria solani* control. During the summer experiment *Bacillus subtilis* (SerenadeTM, Bayer Crop Science, Germany) and mancozeb (Mancozeb 80 PH$^{TM}$, Adama, Mexico) were sprayed in all plots for *Leveillula* sp. control on 06/08/2014 and 20/09/2014, respectively. All products were sprayed at the dose recommended on the labels and using a motorized backpack sprayer (Arimitsu$^{TM}$, Osaka, Japan) operating at 1723.7 Kpa (250 PSI) and special care was taken to cover all leaf surfaces. All products were selected due to its expected harmlessness for the predator according to existing data on other mirid bugs (http://side-effects.koppert.nl).

### Sampling

Plants were monitored weekly for 14 and 16 weeks during the fall-winter and summer experiments, respectively. In both cases, evaluations started one week after planting. Numbers of nymphs plus pupae and adults of psyllids and whiteflies and mirids nymphs and adults, as well as necrotic rings (characteristic symptom of phytophagy on leaves produced by mirids) were counted on three leaves: one from the upper, one from the middle and one from the bottom third of each of ten randomly selected plants per plot. In each case, leaves were turned carefully to count first whitefly, psyllids and *D. hesperus* adults, and then the other insect stages using a 15× hand lens. Additionally, effects of plant feeding by the predator were assessed on flowering clusters and fruits. Fifteen fully opened flowering clusters (third from the top of the plant) per plot were randomly selected in each sampling and then the number of non-injured, injured (viable but presenting necrotic rings) and aborted flowers were counted in situ. Ten green growing fruits were also randomly selected in each plot in each sampling. They were placed into a plastic bag which was brought to the laboratory where the number of feeding punctures (punctures surrounded by a yellowish bleached area) were counted under a dissection microscope (40×). Fruits were always collected from the fifth clusters (starting from the top) of the plants.

### Statistical analysis

Treatment effects on whitefly and psyllid in each experiment were analyzed with linear mixed effects models, with time (weeks) as random factor nested in blocks (greenhouse) to correct for pseudoreplication due to repeated measures. Thereafter, treatments were compared through model simplification by combining treatments (Crawley 2002). Numbers of nymphs and adults of whitefly and psyllid were log (x + 1) transformed prior to analysis to stabilize error variance. In all cases untransformed values are given in tables and figures. Abbott's formula 100 × [(1-(treated/control)] (Abbott 1925) was used to represent the degree of whitefly and psyllid nymphal and adult suppression in response to *D. hesperus*. Seasonal means were used to estimate degree of pest suppression in each experiment.

## Results

### Dicyphus hesperus

The number of *D. hesperus* per leaf remained relatively low during the first five weeks after the release in the fall-winter experiment (Fig. 1a), but increased rapidly afterwards when the second generation appeared in the crop peaking at week 7 at above 0.3 individuals per leaf. Subsequently, the population density dropped slightly but increased to above 0.4 individuals per leaf at the end of the experiment. During the summer experiment

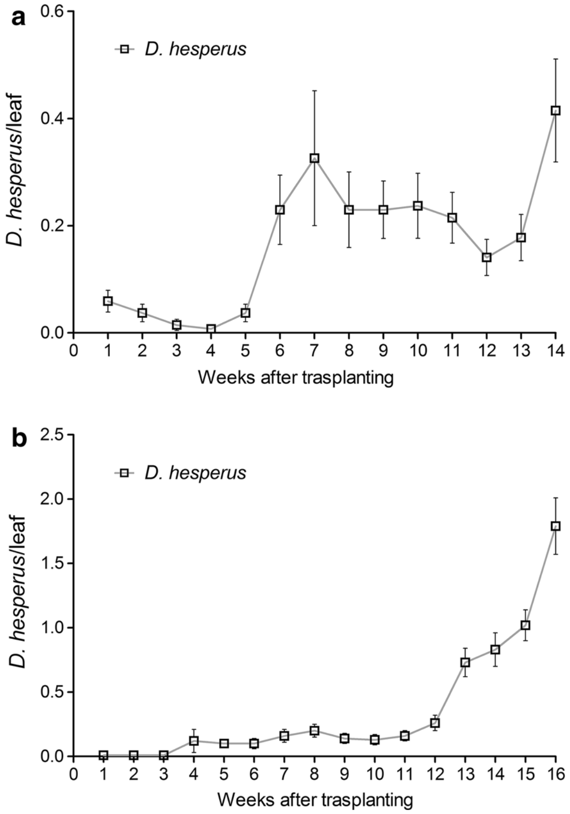

**Fig. 1** Mean (±SE) of nymphs plus adults of *Dicyphus hesperus* per leaf in the fall-winter (**a**) and summer (**b**) experiments in plots receiving the predator

numbers of *D. hesperus* were progressively higher throughout the experiment and its density at the end of the experiment was, on average, higher than in the fall-winter experiment (Fig. 1b).

## Pests control

### *Fall-winter experiment*

During the first half of the fall-winter experiment (weeks 1–8), the number of whitefly adults per leaf was similar between plots with or without *D. hesperus* (Fig. 2a). Thereafter, the number of whitefly adults per leaf steadily increased in No *D. hesperus* plots until the end of the experiment, resulting in a significantly higher population density of whitefly adults compared to plots receiving the predator ($F_{1,45} = 126.15$; $P < 0.001$). This amounted to a 88.8 % decrease of whitefly adults compared to plots without *D. hesperus* according to Abbott's formula. Numbers of whitefly nymphs per leaf followed a similar pattern (Fig. 2b), and significantly fewer whitefly nymphs were recorded in plots receiving *D. hesperus* ($F_{1,45} = 96.51$; $P < 0.001$), amounting to a 79.4 % decrease compared to control plots.

The density of psyllid nymphs and adults per leaf remained close to zero for the entire fall-winter experiment in plots receiving *D. hesperus* (Fig. 2c, d), whereas numbers of nymphs and adults of psyllid per leaf increased rapidly from the sixth and eighth week, respectively, in plots without the predator. Consequently, the overall abundance of psyllid nymphs and adults were significantly lower in plots with *D. hesperus* (adults: $F_{1,45} = 58.10$; $P < 0.001$; nymphs: $F_{1,45} = 68.75$; $P < 0.001$) and the degree of psyllid adult and nymph suppression in cages treated with the predator was 88.2 and 90.1 %, respectively.

### *Summer experiment*

During the first weeks of the summer experiment, the number of whitefly adults and nymphs per leaf were

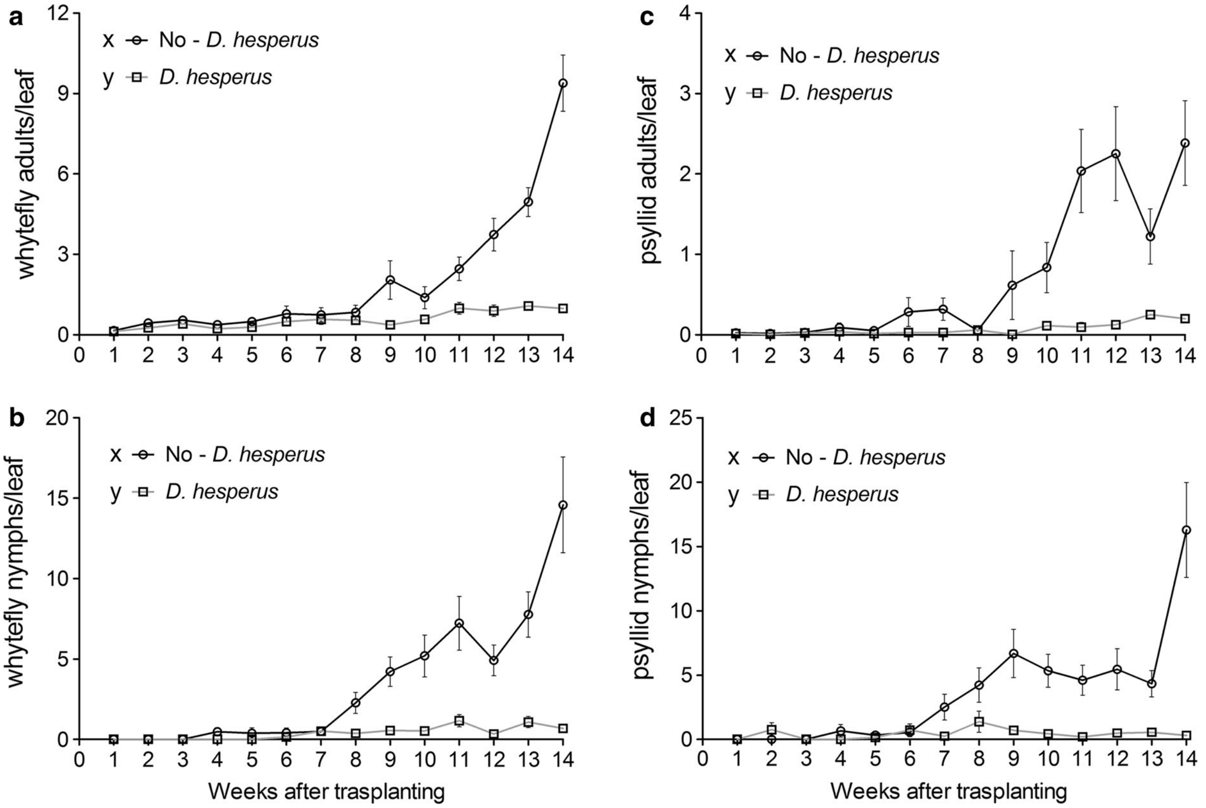

**Fig. 2** Dynamics of pests during the fall-winter experiment: Mean (±SE) adults (**a**) and nymphs (**b**) of *Bemisia tabaci* per leaf and adults (**c**) and nymphs (**d**) of *Bactericera cockerelli* per leaf in each treatment

again similar in all plots (Fig. 3a, b), but the growth of whitefly nymphs and adults per leaf was more pronounced in plots with the pest only thereafter, resulting in a higher abundance of both nymphs and adults in the No *D. hesperus* plots (Adults: $F_{1,45} = 139.95$; $P < 0.001$; Nymphs: $F_{1,45} = 27.026$; $P < 0.001$). The degree of whitefly nymphs and adults suppression was 77.6 and 79.5 %, respectively in response to *D. hesperus*.

Density of psyllid adults remained at low levels during the first weeks of the experiment in all plots (Fig. 3c) and started to increase progressively from the ninth week onwards. Nevertheless, population growth was greater in No *D. hesperus* plots, resulting in a higher density of psyllid adults compared to plots receiving the predator ($F_{1,45} = 114.05$; $P < 0.001$), where suppression of psyllid adults reached 94.5 % in response to *D. hesperus*. The dynamic of psyllid nymphs population was also similar between treatments during the first weeks of the summer experiment (Fig. 3d). Nevertheless, numbers of nymphs per leaf increased rapidly after the twelfth week to the end of the trial in plots without predator release. In contrast, population density of psyllid nymphs remained nearly constant during the entire experiment in plots receiving the predator and consequently abundance of psyllid nymphs was significantly lower compared to the No *D. hesperus* plots ($F_{1,45} = 248.18$; $P < 0.001$) and the degree of pest suppression reached 81.2 % in response to the predator.

## Phytophagy

Neither damage on flowers nor on leaves were observed during either the fall-winter or summer experiment. Nevertheless, feeding punctures on fruits were recorded in both seasons, but always at low levels. During the fall-winter they were only observed in the last week, averaging at 0.23 ± 0.10 punctures

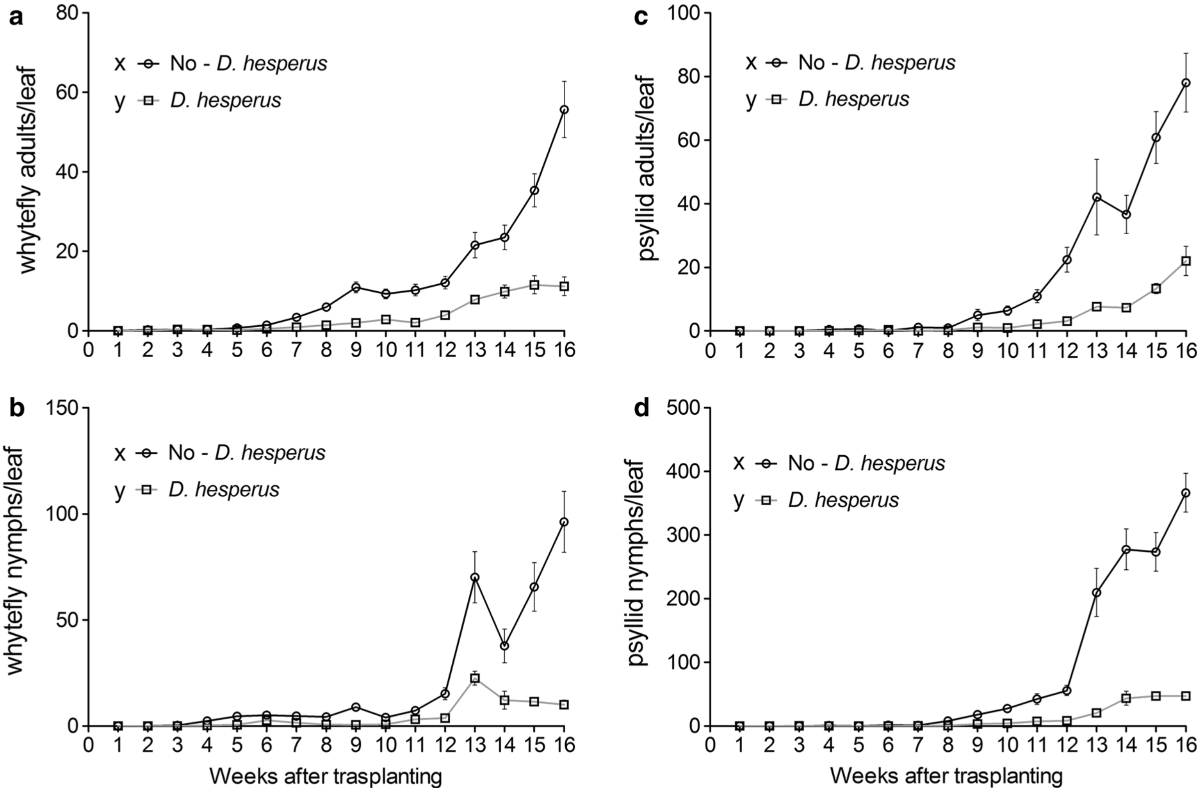

**Fig. 3** Dynamics of pests during the summer experiment: Mean (±SE) adults (**a**) and nymphs (**b**) of *Bemisia tabaci* per leaf and adults (**c**) and nymphs (**d**) of *Bactericera cockerelli* per leaf in each treatment

per fruit. In the summer experiment they were recorded in weeks 2, 3 and 5, but the maximum number of feeding punctures per fruit was 0.3 ± 0.12.

## Discussion

*Dicyphus hesperus* established well on tomato during both the winter and summer experiments, although population density was, on average, higher during summer, presumably due to the higher temperature and food availability when compared to the fall-winter experiment. Nevertheless, densities during both trials were sufficient to provide a high degree of pest suppression. These results indicate that the predator is highly effective against both pests, and can be used against them in a wide range of climatic conditions, including most greenhouse conditions of North America. Earlier studies have already reported good whitefly control by *D. hesperus* in greenhouse tomato and also demonstrated its capability to reduce populations of other pests such as *F. occidentalis* or *Tetranychus urticae* Koch (Acari: Tetranychidae) (McGregor et al. 1999; Shipp and Wang 2006). Nevertheless, to our knowledge, there has not been previous study of the successful use of *D. hesperus*, or other predator, as a biological control agent of *B. cockerelli* on tomato. The option of targeting two or more pests with a single natural enemy is highly favorable for biocontrol. Likewise, it reduces the complexity and costs of the biological control and increases likelihood of establishment and preservation of the predator in periods of prey scarcity. Nevertheless, the combination of *D. hesperus* with other enemies could give greater positive results. Although, *D. hesperus* greatly suppressed whitefly and psyllid densities, there was still some room to increase the effectiveness against the pests, especially taking into account their high efficiency in transmitting plant diseases. Thus, supplementary releases of parasitic wasps such as *E. eremicus* or *E. formosa* against whitefly and *T. triozae* against psyllid could provide additional control. Nevertheless, such combinations should be tested before they are used in practice to determinate their viability in terms of costs and the possible generation of undesirable interactions in the suppression of the herbivore, owing to niche complementarity, functional redundancy, and/or intraguild predation (Straub et al. 2008).

*Dicyphus hesperus* has been previously investigated for biological control of pests of greenhouse grown tomatoes in Canada. Gillespie and McGregor (2000) and McGregor et al. (1999, 2000) reported good results in research greenhouses, but initially growers who released the predator in commercial tomato greenhouses, especially when prey populations were very low or absent, found that it took a long time to increase to sufficient numbers to keep pests under control and ultimately failed to persist in the crop (Gillespie et al. 2007). Later, Sánchez et al. (2003, 2004) found that the use in tomato greenhouses of the mullein plants, *Verbascum thapsus* L. as banker plants, allowed reproduction and development of *D. hesperus* in the absence of prey, thus enhancing the establishment of *D. hesperus* and increasing its impact on pest populations. Our observations make us think that addition of *E. kuehniella* eggs would have similar effects. It allowed establishment of the predator which ultimately resulted in a high degree of pest suppression. Moreover usage of *E. kuehniella* eggs to support predator populations on tomato would provide some biological and technical benefits. Sánchez et al. (2004) estimated greater reproductive and developing parameters when *D. hesperus* had access to *E. kuehniella*, and thus development of nymphs should be faster and survivorship of nymphs and longevity and fecundity of females should be greater when eggs of *E. kuehniella* are added.

One negative aspect of the use of predatory mirids for biological control is their potential for plant damage. Phytophagy can provide benefits for omnivorous insects. It allows them to survive feeding on plants in periods of prey scarcity (Naranjo and Gibson 1996; Alomar and Wiedenmann 1996) and may enhance their fitness when they also feed on prey (Coll and Guershon 2002; Naranjo and Gibson 1996). However, phytophagy sometimes results in direct damage to the crop (Calvo et al. 2009; Castañé et al. 2011; Sánchez 2008). In the case of *D. hesperus*, plant feeding normally increases with increased prey feeding, but under some circumstances it can be independent of prey feeding or the predator may switch between plant and prey foods depending on their relative qualities or abundance (Gillespie and McGregor 2000). In fact, Shipp and Wang (2006) founded that feeding damage to tomato fruit by *D. hesperus* was related to the availability of prey (predator:prey ratio) under greenhouse conditions. Similarly, in our experiments where the predator always had access to prey, we did not observe feeding damage on leaves or growing parts of the plant and fruit feeding was minimal and for a short time period. This suggests that fruit feeding could be related to prey availability. Our results suggest that utilization of *D. hesperus* would not result in significant plant damage, at least in the presence of arthropod prey or other food source. Gillespie et al. (2007) also came to the same conclusion, suggesting that use of the predator on tomato crops should not be constrained by fruit damage. Overall, our results demonstrate that addition of augmentative releases of *D. hesperus* to the IPM toolbox would improve biologically-based management strategies in tomato and presumably help to increase adoption of such programmes in tomato in North America. However, augmentative releases of the predator should be tested under field conditions in commercial tomato greenhouses to confirm these results before it can be recommended as a biological control agent for whitefly and psyllid control.

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